On the Performance Evaluation of Two Novel Fractional Frequency Reuse Approaches for OFDMA Multi-User Multi-Cellular Networks

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Abstract

The paper studies two resource allocation strategies (**GRID**, **anti-EMI**) for **multi-user OFDMA systems**. These strategies are evaluated after being compared with the **Round Robin** and the **FFR strategies** in terms of mean throughput and mean dissipated power. All investigated strategies assign resources without Channel State Information (**no CSI**), while both GRID and anti-EMI inherently **combat Co-Channel Interference** (CCI); hence they enhance mean throughput. Simulations indicate that GRID outperforms Round Robin and FFR in all scenarios into consideration and competes the anti-EMI strategy in various network orientations. The latter is justified especially for highly populated scenarios, i.e. 50% probability failure and 2 subcarriers per Mobile Terminal (MT). As for the FFR strategy, simulations verify that the spectral efficiency is not the optimum, which fact has been already verified in the respective literature as well. Finally, the platform can inherently spare around the 70% of the maximum available power.

Keywords: *OFDMA; Resource Allocation Management; FFR; Inter-Cell Interference Coordination*

Author's Biography

Maria A. Seimeni was born in Arta, Greece, in July 1982. She received her Dipl.-Ing. degree from Democritus University of Thrace (DUTh) in electrical and computer engineering (ECE) in 2007, her M.Sc in Systems Engineering from Politecnico di Torino (PoliTo) in 2009 and her Ph.D. degree from the National Technical University of Athens (NTUA) in electrical and computer engineering (ECE) in 2016. She is currently working as a postdoctoral researcher in the Intelligent Communication & Broadband Networks Laboratory (ICBNet) and the Microwaves & Fiber Optics Laboratory (MFOL) of NTUA. She has collaborated with the University of Twente in the frame of the COST ACTION 1407-ACCREDIT and has been a teaching staff member of the Space MSc Program supported by both the National Observatory of Athens (NoA) and the University of Peloponnese (UoP). During the period 2007-2009, she was working at Alenia Aeronautica S.p.A. on EMC issues, while she has established a cooperation with Airbus Defence and Space since 2016. Since 2014, she has been a scientific consultant for space industry around Europe, while in 2017 Maria joined Singular Logic SA, where she is responsible for the management of ESA contracts. Maria Seimeni is also a reviewer in peer-reviewed International Scientific Journals and Conferences, acts as an expert evaluator in the H2020 Programme, while she has received international distinctions in her fields of expertise. Overall, Maria has been involved in ESA projects, aerospace projects, as well as international and national research projects. Her scientific interests are in the field of spectrum exploitation by wireless OFDMA/MIMO systems, EMC and microwave circuits.

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Network System Architecture

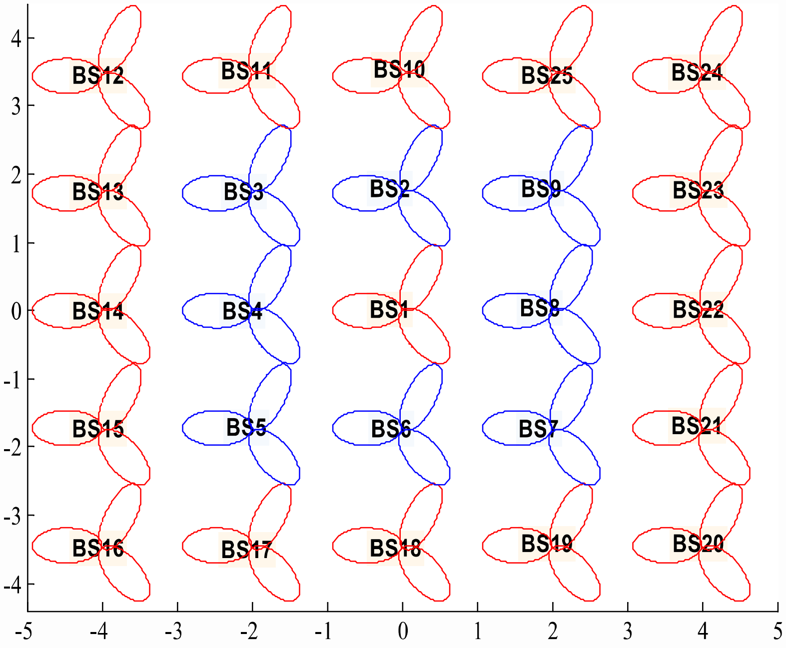


Fig. 1: A two-tiers cellular network.

Parameter	Value/Assumption
Cell radius/ Tiers	1Km/ 1 and 2
BS/MT height	30/1.5 m
Propagation	Okumura-Hata, pathloss exponent 3.5
Standard deviation for shadow fading	8 dB
Azimuth dispersion	Laplacian distribution, azimuth spread 5°
Radiation pattern of the antenna element (3-beams)	Broadside gain = 14 dBi 3-dB beamwidth = 70° Front-to-back ratio = 20 dB

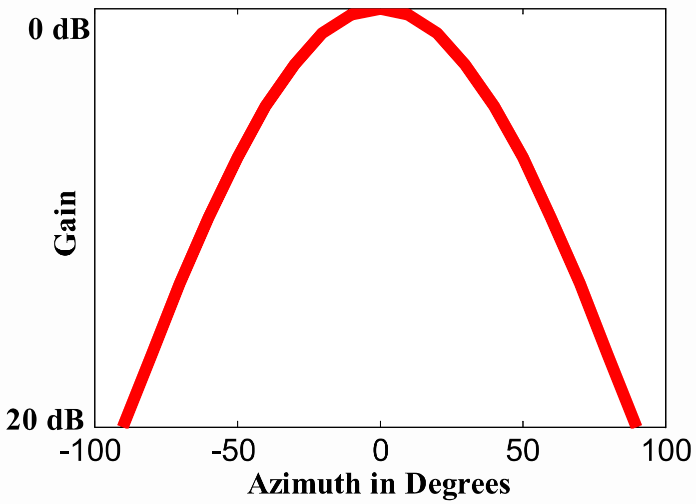


Fig. 2: 3-sector radiation pattern mask

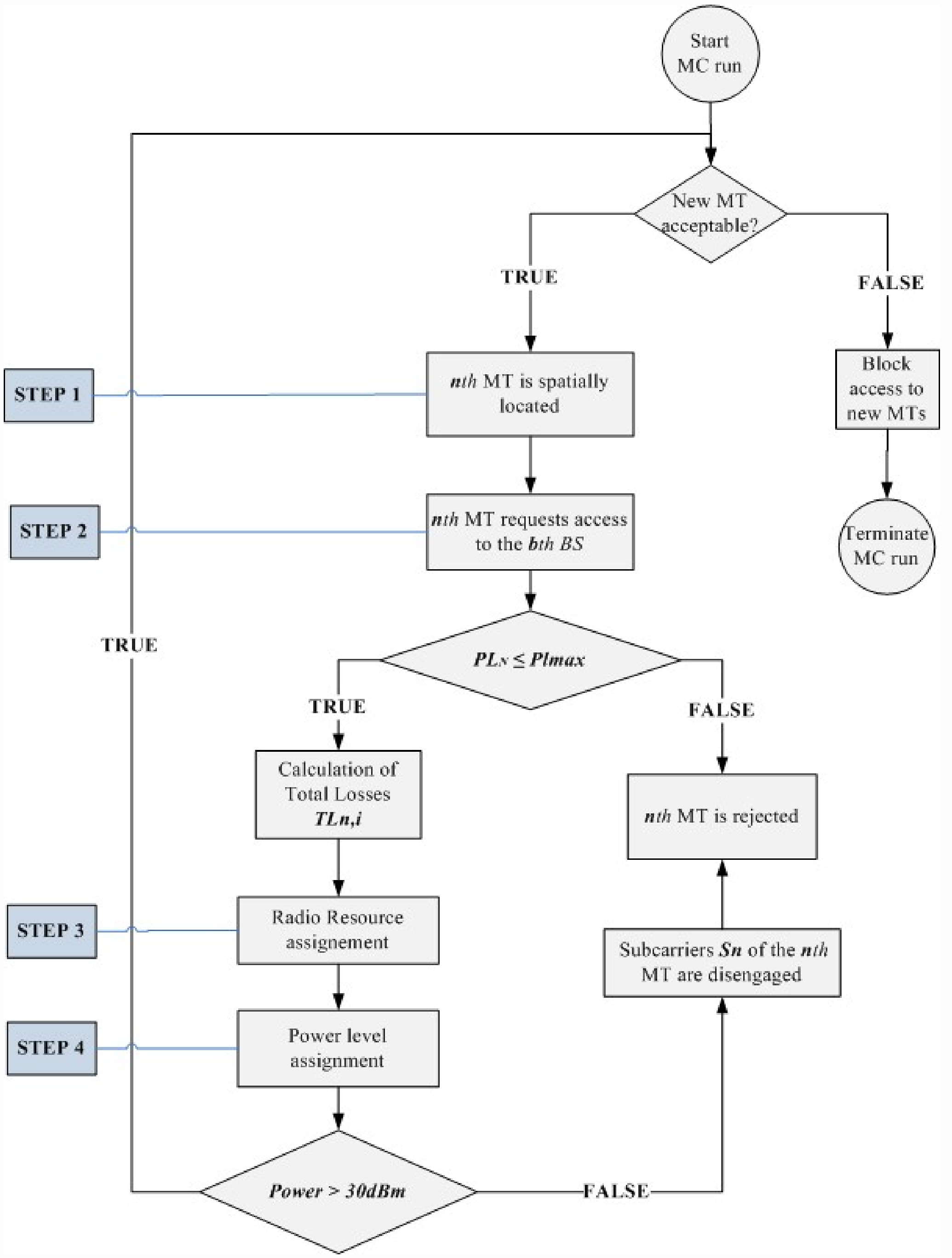
Network Traffic Scenarios

To evaluate the strategies on a common basis, **fixed** number of **subcarriers/MT** is considered.:-

- The **capacity-power problem** is relatively **simplified**,
- The **MTs** are permitted to **judiciously have access at PHY layer.**

Parameter	Value/Assumption
Carrier frequency	2.5 GHz
Maximum power per BS/MT	43/30 dBm
Probability Failure	30%, 50%
SINR/ Total Bandwidth	9.6 dB/ 10 MHz
Bandwidth per subcarrier	78.125 KHz
Thermal noise level at MTs (I_{noise})	-104 dBm
Total subcarriers per sector	128
Subcarriers per MT	1,2,5

Monte Carlo Simulations Flow



Resource Allocation Algorithms

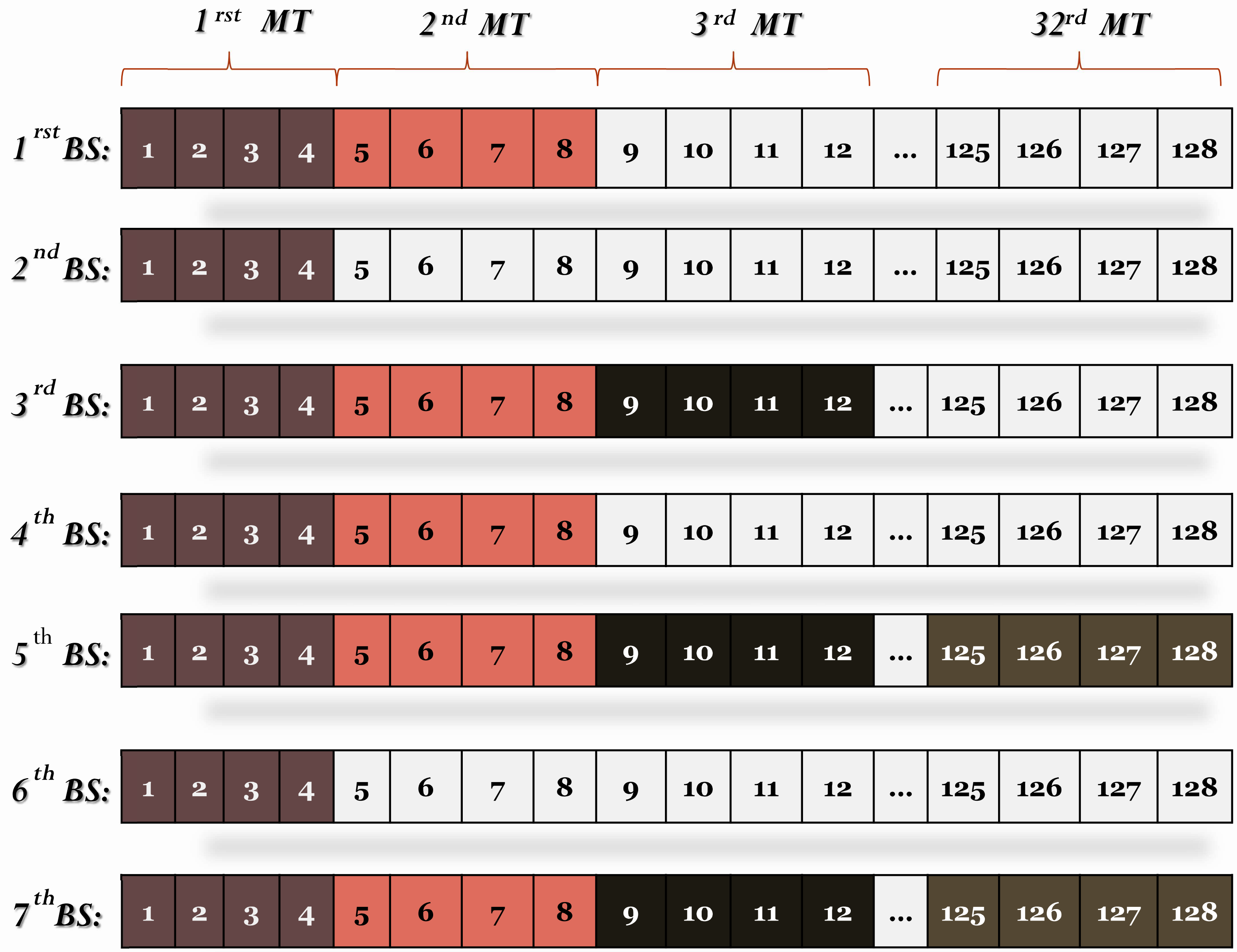
- **Round Robin** Algorithm
- enhanced **F**ractional **F**requency **R**euse Algorithm
- **GRID** Algorithm
- **Anti-EMI** Algorithm

Resource Allocation Algorithms (1a/4)

***Round Robin*:-**

*The first **Sn available subcarriers** of the b^{th} **BS** are assigned to the n^{th} MT.*

***Scenario*: 1 tier (# 7 BSs) and #4 OFDM subcarriers per MT per network orientation**



	1rst MT				2nd MT				3rd MT					32rd MT			
1rst BS:	1	2	3	4	5	6	7	8	9	10	11	12	…	125	126	127	128
2nd BS:	1	2	3	4	5	6	7	8	9	10	11	12	…	125	126	127	128
3rd BS:	1	2	3	4	5	6	7	8	9	10	11	12	…	125	126	127	128
4th BS:	1	2	3	4	5	6	7	8	9	10	11	12	…	125	126	127	128
5th BS:	1	2	3	4	5	6	7	8	9	10	11	12	…	125	126	127	128
6th BS:	1	2	3	4	5	6	7	8	9	10	11	12	…	125	126	127	128
7th BS:	1	2	3	4	5	6	7	8	9	10	11	12	…	125	126	127	128

Resource Allocation Algorithms (1b/4)

Round Robin:-

*The first **Sn available subcarriers** of the* ***b^{th} BS*** *are assigned to the* ***n^{th} MT.***

- Given that the sets of **different coloured OFDM subcarriers** indicate a MT (**previous slide example**), each BS allows a certain number of MTs access to the network and its services:-

Base Station	No. of Terminals
1	# 02
2	# 01
3	# 03
4	# 02
5	# 32
6	# 01
7	# 32

Comment:-

The algorithm **lacks intelligence**, for it **does not consider Inter-Cell Co-Channel Interference**.

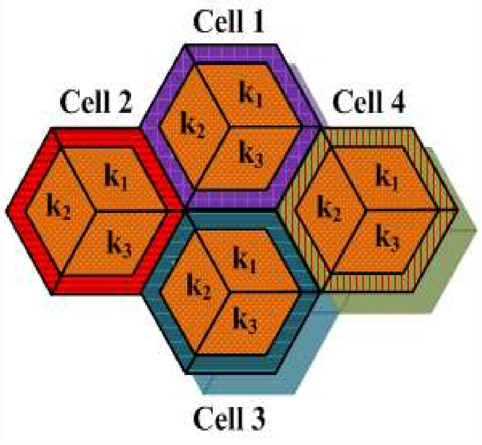
$$U_n \leftarrow C_b(1:S_n)$$
$$C_b \leftarrow C_b \setminus U_n$$

Variable	Description
n	The nth MT
b	The bth BS that serves the nth MT
Un	Subset of the Cb and set of OFDM subcarriers assigned to the nth MT
Cb	Available OFDM subcarriers of the bth BS
Sn	Number of OFDM subcarriers assigned to the nth MT

Resource Allocation Algorithms (2/4)

enhanced Fractional Frequency Reuse:-

*Likewise the traditional FFR strategy, the **inner sub-regions** are assigned the **same subset of OFDM subcarriers**, but at **different power levels** (p_1, p_3, p_5, p_2, etc.). The remaining subset of subcarriers is **orthogonally partitioned.***



Comment:-

The algorithm leads to **low spectral efficiency**, for each BS **does not exploit all available sub-bands (SB)**.

$$k_1 = k_2 = k_3$$
$$k_{1,\text{Cell 1}} = \{SB_1(p_1,r_1), SB_2(p_2,r_2)\}$$
$$k_{1,\text{Cell 2}} = \{SB_1(p_3,r_1), SB_3(p_4,r_2)\}$$
$$k_{1,\text{Cell 3}} = \{SB_1(p_5,r_1), SB_4(p_6,r_2)\}$$
$$k_{1,\text{Cell 4}} = \{SB_1(p_8,r_1), SB_5(p_7,r_2)\}$$

The FFR scheme per sector (k1, k2, k3)

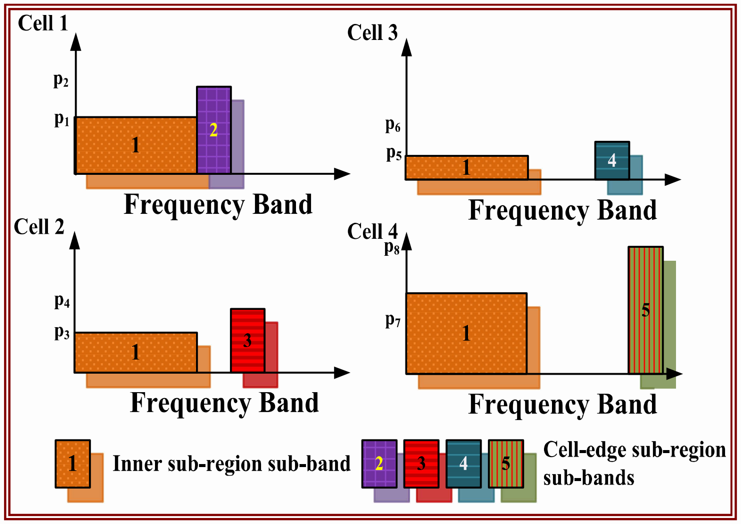


Fig. 1: Power levels and SBs for four cell types

The MT is randomly assigned OFDM subcarriers from the SB of its corresponding sub-region (***r1*** or ***r2***) via ***randsample(i,D)***[1].

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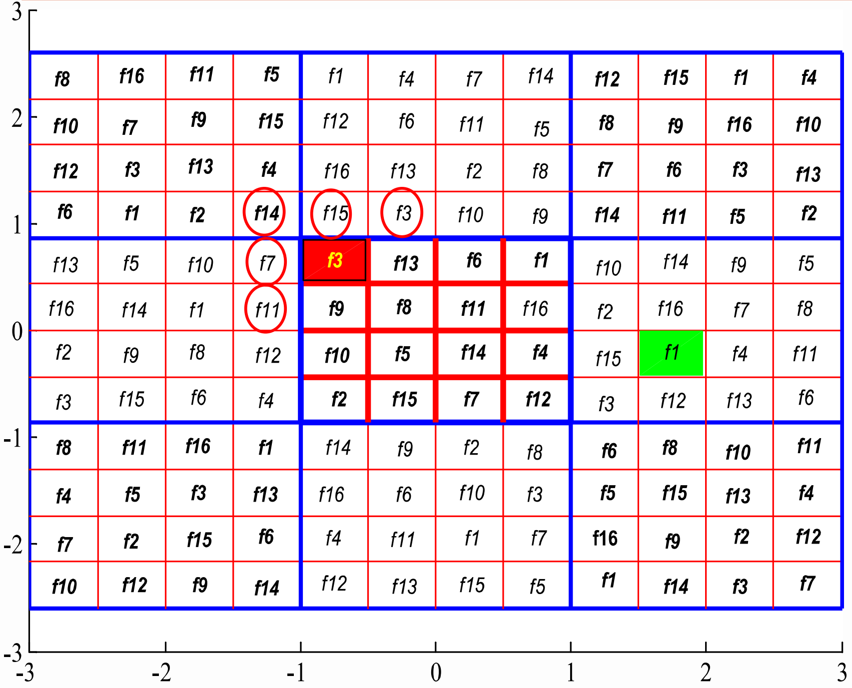
[1] The function returns randomly ***i*** elements from ***D*** set.

Resource Allocation Algorithms (3a/4)

GRID :-

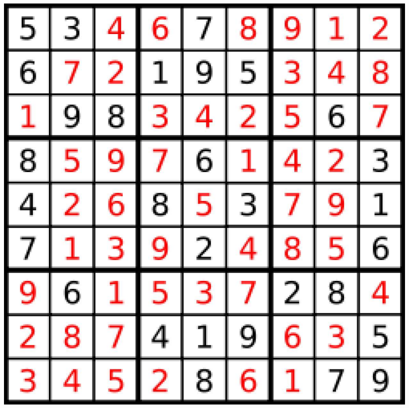
Based on the **SUDOKU** mechanism



f8	f16	f11	f5	f1	f4	f7	f14	f12	f15	f1	f4
f10	f7	f9	f15	f12	f6	f11	f5	f8	f9	f16	f10
f12	f3	f13	f4	f16	f13	f2	f8	f7	f6	f3	f13
f6	f1	f2	f14	f15	f3	f10	f9	f14	f11	f5	f2
f13	f5	f10	f7	f3	f13	f6	f1	f10	f14	f9	f5
f16	f14	f1	f11	f9	f8	f11	f16	f2	f16	f7	f8
f2	f9	f8	f12	f10	f5	f14	f4	f15	f1	f4	f11
f3	f15	f6	f4	f2	f15	f7	f12	f3	f12	f13	f6
f8	f11	f16	f1	f14	f9	f2	f8	f6	f8	f10	f11
f4	f5	f3	f13	f16	f6	f10	f3	f5	f15	f13	f4
f7	f2	f15	f6	f4	f11	f1	f7	f16	f9	f2	f12
f10	f12	f9	f14	f12	f13	f15	f5	f1	f14	f3	f7

Fig. 2: Blocks and sub-blocks for 1 tier of BSs (G =16). Subcarrier frequency subsets per sub-block per block. Edge sub-block and inner sub-block .

≈



5	3	4	6	7	8	9	1	2
6	7	2	1	9	5	3	4	8
1	9	8	3	4	2	5	6	7
8	5	9	7	6	1	4	2	3
4	2	6	8	5	3	7	9	1
7	1	3	9	2	4	8	5	6
9	6	1	5	3	7	2	8	4
2	8	7	4	1	9	6	3	5
3	4	5	2	8	6	1	7	9

Fig. 3: A typical SUDOKU puzzle

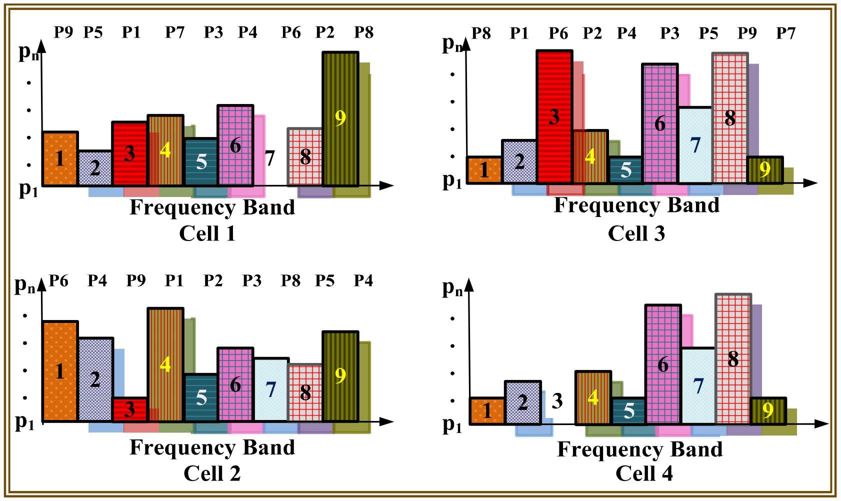


Fig. 4: Power levels and SBs for four cell types

Resource Allocation Algorithms (3b/4)

GRID :-

Based on the **SUDOKU** mechanism

```
(1) $length(f) = floor(C/G), \forall f \in F$
(2) $for \quad 1 \le b \le B$
(3)     $for \quad 1 \le j \le |F|$
(4)         $g_b \leftarrow randsample(1, G_b)$
(5)         $G_b \leftarrow G_b \setminus g_b$
(6)         $f_{g_{b,n}} \leftarrow [(j-1)*length(f)+1]:[j*length(f)]$
(7)     $end$
(8) $end$
```

TABLE I. Function **grid()**.

```
(01) $if \quad b == b'$
(02)     $g_{b,n} \leftarrow g_b$
(03) $else$
(04)     $g_{b,n} \leftarrow randsample(1, G_b)$
(05) $end \quad (if\_in\_line\_1)$
(06) $if \quad f_{g_{b,n}} = \varnothing, \quad for \quad \forall g \in G_b$
(07)     $U_n \leftarrow randsample(S_n, (|C_b| - rem(|C_b|, G) + 1) : |C_b|)$
(08) $else$
(09)     $if \quad f_{g_{b,n}} \ne \varnothing$
(10)         $U_n \leftarrow randsample(S_n, f_{g_{b,n}})$
(11)     $else$
(12)         $if \quad g_{b,n} \quad edge \quad sub-block$
(13)             $g_{b,n} \leftarrow g_{b,l}$
(14)         $elseif \quad g_{b,n} \quad inner \quad sub-block$
(15)             $g_{b,n} \leftarrow randsample(1, G_b)$
(16)         $end \quad (if\_in\_line\_14)$
(17)         $U_n \leftarrow randsample(S_n, f_{g_{b,n}})$
(18)     $end \quad (if\_in\_line\_10)$
(19) $end \quad (if\_in\_line\_6)$
(20) $f_{g_{b,n}} \leftarrow f_{g_{b,n}} \setminus U_n$
(21) $C_b \leftarrow C_b \setminus U_n$
```

TABLE II. **GRID()** ALGORITHM.

Resource Allocation Algorithms (3c/4)

GRID **:-**

Based on the ***SUDOKU*** *mechanism*

Comments:-

a. The algorithm **conceptually grids the spatial area into disjoint equal blocks** (**blue rectangles**)

b. Each block is further partitioned in **disjoint equal sub-blocks** (**red rectangles**).

c. **“Virtual” 1-1 pre-matching** between **subsets** of subcarrier frequencies **and sub-blocks**, (*Table I, Line 6*).

d. OFDM subcarriers subsets **appear once in each block**, all subsets **have equal lengths** and are **disjoint**.

e. **Subcarriers** are extracted from the subset, which corresponds to the **MT’s sub-block** (*Table II, Lines 09-10*). Otherwise, the terminal borrows subcarriers from other subcarrier subsets of b^{th} BS.

f. If $g_{b,n}$ is an ***edge sub-block*** (*Table II, Lines 12-13*: e.g. *red sub-block*) then the new subcarrier subset must be wisely selected (**avoid interference issues**). The MT **must not reserve** radio resources from **subcarrier** subsets which are also assigned to *edge sub-blocks* of neighbouring BSs (***Jamming Edge Sub-Blocks, J***).

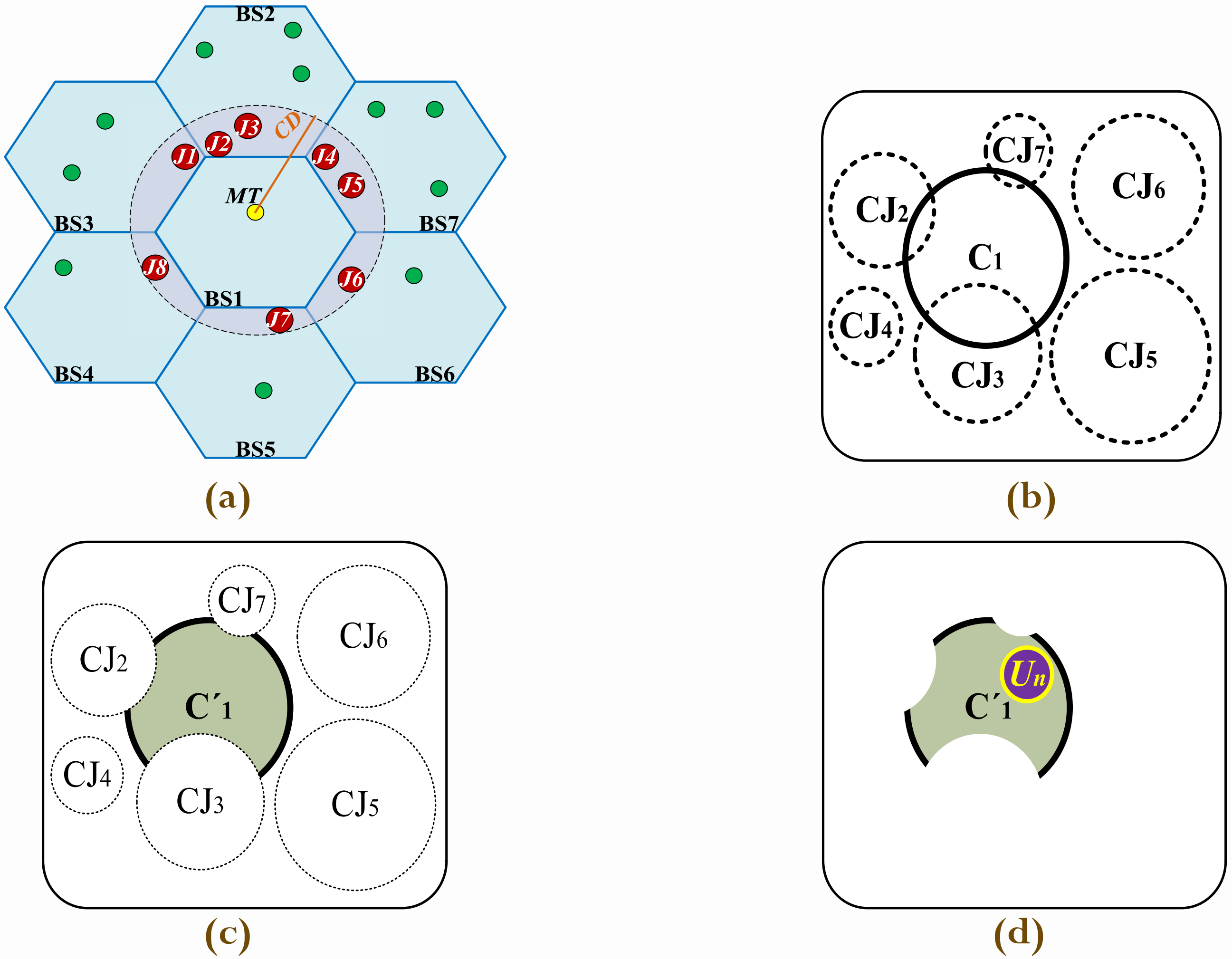
g. An ***inner sub-block*** is considered to be the one of the BS8 filled with **light green** light green

h. Each sub-block of each cell is **dynamically assigned a power level**.

Resource Allocation Algorithms (4a/4)

Anti-EMI **:-**

dynamically protects each terminal against CCI *by avoiding the allocation of the subcarriers which are reused* ***Jammers,*** *hence, CCI is mitigated.*



(a) (b) (c) (d)

Fig. 5: (a) a MT and its Jammers. Venn diagram for:- (b) the available subcarriers C1 of BS1 and the CJ subcarriers that are engaged by the Jammers. (c) The subset C'1 of the available subcarriers of the BS1 that can be engaged by the MT. (d) The Un set of subcarriers that are finally engaged by the MT.

Resource Allocation Algorithms (4b/4)

Anti-EMI **:-**

dynamically protects each terminal against CCI *by avoiding the allocation of the subcarriers which are reused* **Jammers,**[2] *hence, CCI is mitigated.*

Comments:-

a. For each ***n^th^*** **MT**, **the strategy virtually partitions the area around it into two sub-regions** according to ***Jammers' Range*** (***JR***).

b. MTs of the neighboring BSs are classified into ***Jammers*** and ***non-Jammers***.

c. non-Jammers'* subcarriers create** the ***Wish List, thanks to the **interoperability between the neighboring BSs and the *n^th^* MT**.

d. The ***Wish List*** **is communicated** between the cells through **X2 interface**.

```
if    $C_b \cap C^*_{CJ} = \varnothing$
          $C_b \leftarrow C_b$
else                                          →   $U_n \leftarrow randsample(S_n, C_b)$
                                                   $C_b \leftarrow C_b \setminus U_n$
      $C_b \leftarrow C_b \cap C^*_{CJ}$
end
```

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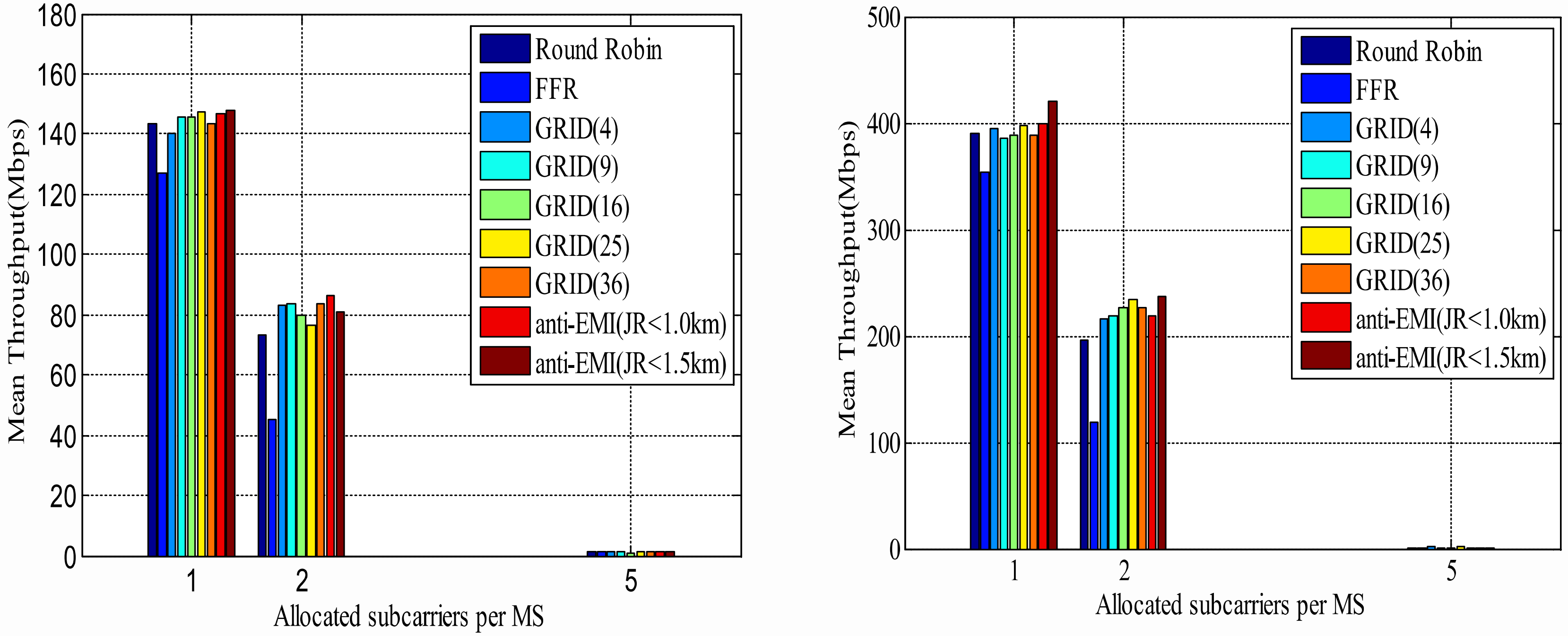
[2] C^*_{CJ} is the set of subcarriers which are not assigned to the ***Jammers***.

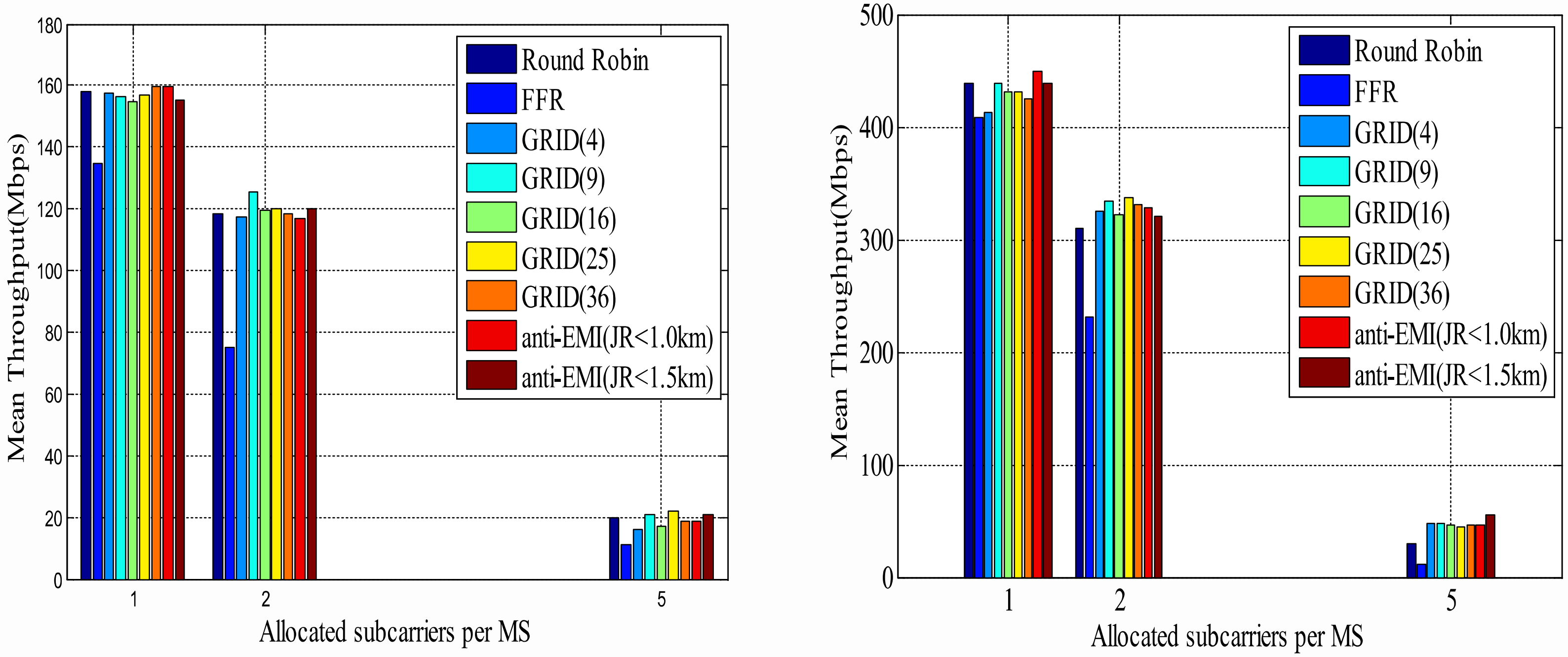
Simulations & Conclusions (1/4)



(a) **(b)**

Fig. 6: Mean Throughput (Kbps) for PF = 30%, (a) 1 tier and (b) 2 tiers.

Simulations & Conclusions (2/4)



(a) **(b)**

Fig. 7: Mean Throughput (Kbps) for PF = 50%, (a) 1 tier and (b) 2 tiers.

Simulations & Conclusions (3/4)

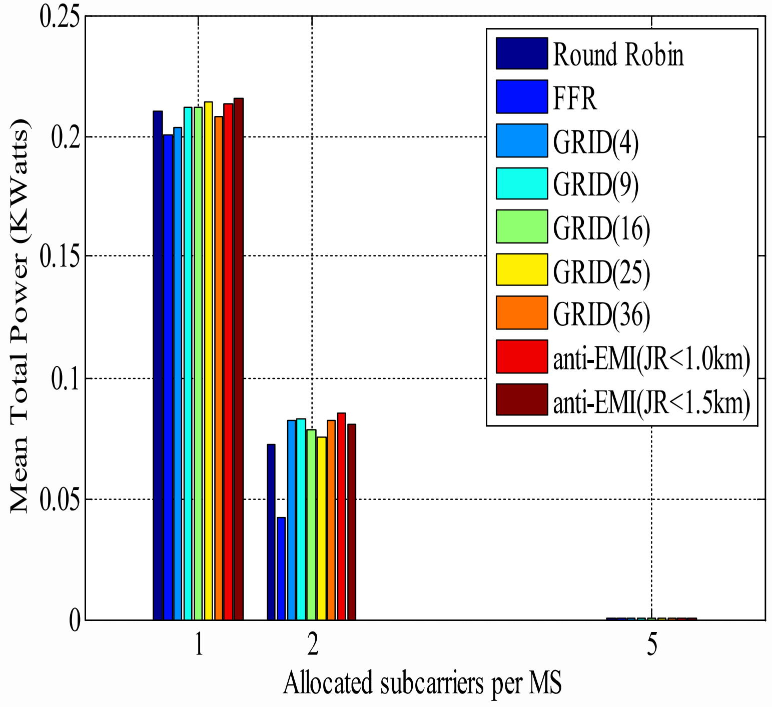


Fig. 8: Mean Total Power (KWatts) for PF = 30%, SINR=9.6dB, 1 tier.

Simulations & Conclusions (4/4)

Comments:-

a. *anti-EMI(JR<1 Km)* performs better than *anti-EMI (JR<1.5 Km)*

b. {**8% mean throughput gain for 30%, 2 tiers and 2 subcarriers/MT**}.

c. *GRID(25)* outperforms all the other configurations [*GRID(16)* is the worst]

***d. GRID* competes *anti-EMI* in most scenarios [*FFR* is the worst]**

e. ***Round Robin* ranks third**, for it assigns to the terminals adjacent subcarriers which in effect experience ***correlated fading***.

f. The **80% (1 subcarrier)** and **50% (2 subcarriers)** approx. of the maximum Throughput is supported respectively [***Fig. 8a***]

g. Less than **90% (1 subcarrier)**, **70% (2 subcarriers)** and **10% (5 subcarriers)** of the maximum Throughput is supported [***Fig. 8b***]

h. **Power Gain equals** the **76% and 67%** respectively for the two cases.

i. **The platform spares around the 70% of the maximum available power**.

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